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(56) Documents Cited

**GB 2260874 A**

**GB 2019695 A**

**EP 0342040 A2**

**US 5251863 A**

(58) Field of Search

**UK CL (Edition O ) G3R RBS RBU , H4J JGA**

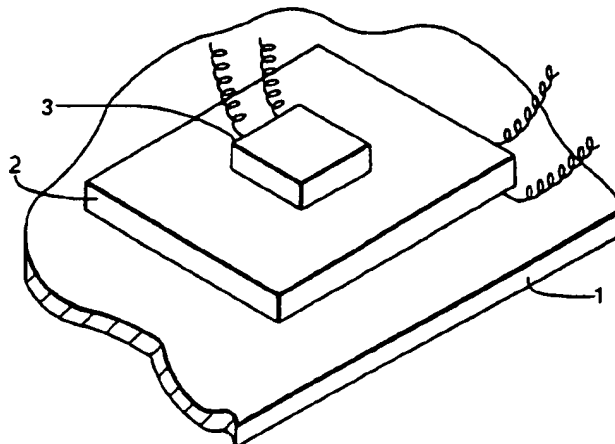
**INT CL<sup>6</sup> G05D 19/02 , G10K 11/178**

**Online: WPI**

(54) **Active vibration damping**

(57) An active vibration damping device comprising a combined piezoelectric actuator (2) and accelerometer (3) adapted to be mounted on a planar member (1) the vibration of which is to be damped. The displacement of the planar member caused by the vibration is detected, and a corresponding inverted signal is applied to the actuator to counteract the vibration. The unit is preferably mounted at a vibration anti-node of the member. Applications include damping of vibrations in circuit boards.

**Fig.2.**



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Fig.1a.

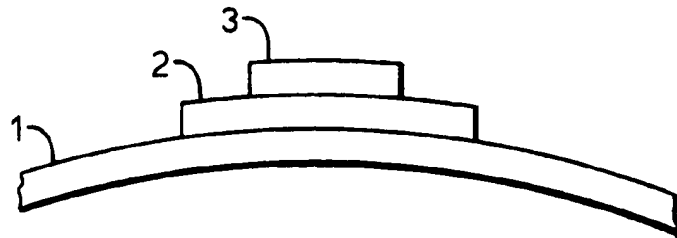


Fig.1b.

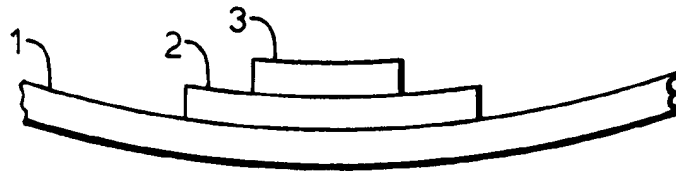


Fig.2.

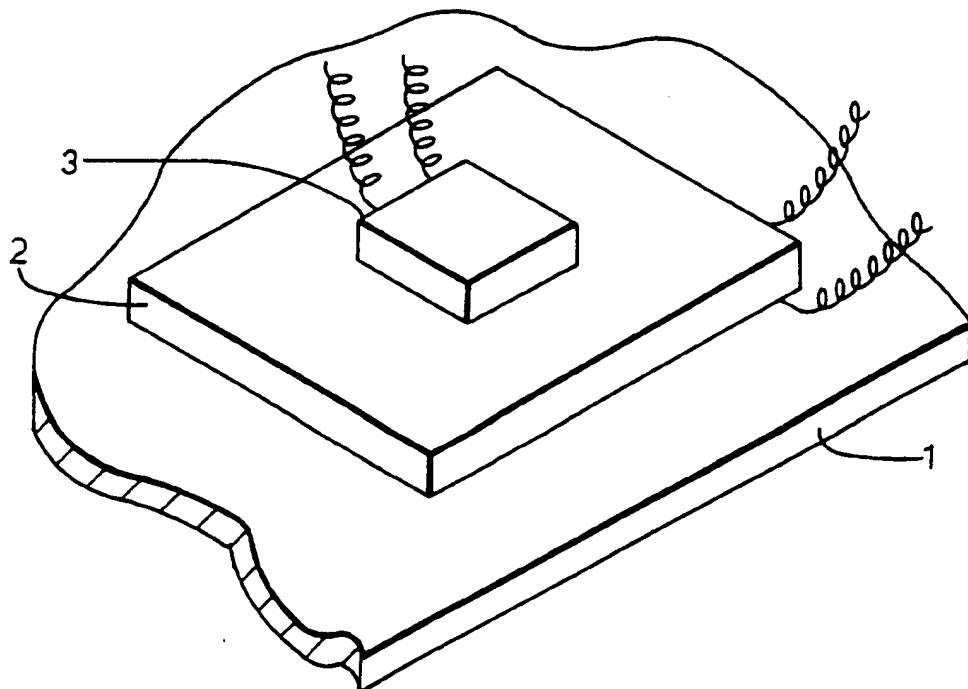


Fig.3.

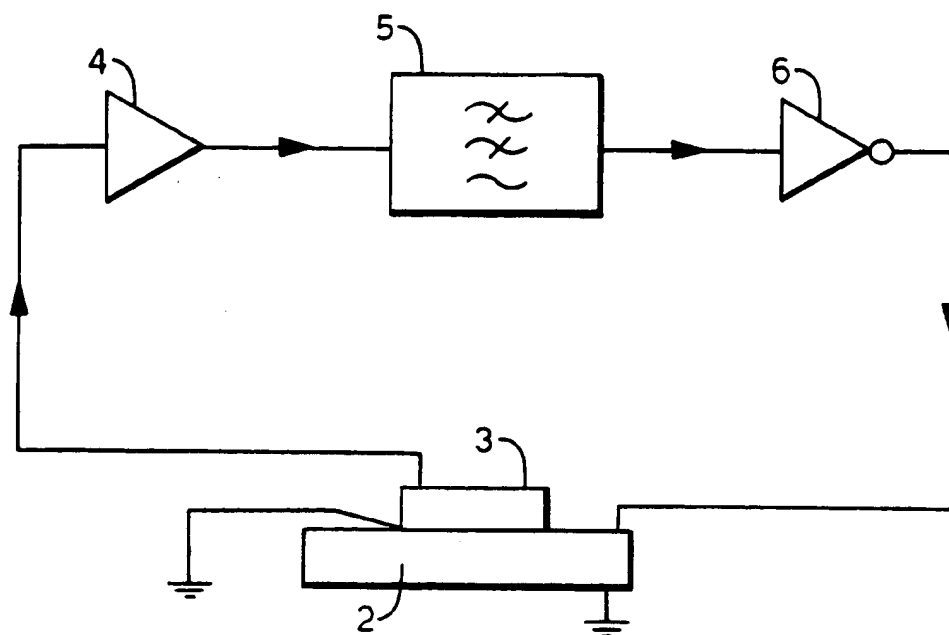
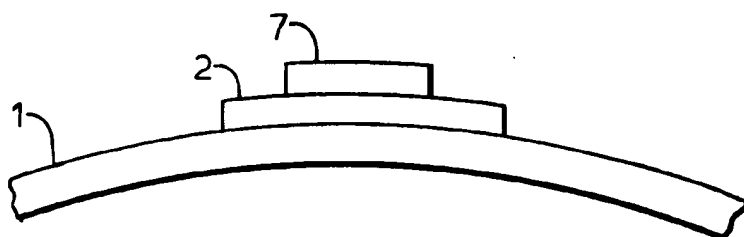


Fig.4.



VIBRATION CONTROL

The present invention relates to vibration control and more particularly to arrangements for controlling the vibration of a planar structure such as a printed circuit board.

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The effects of vibration can be reduced through careful attention to design. This usually involves incorporating within the system additional components to damp the amplitude of vibrations. Passive damping systems can be highly effective and are exploited in many instances. However their utilisation invariably increases the overall size and weight of the assembly and they are least effective at low frequencies, that is below a few hundred hertz.

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An alternative known method for damping vibrations, particularly of planar structures such as aircraft skin panels and electronic printed circuit boards (PCBs), is to use an active system. A typical implementation comprises a piezoceramic sensor, to detect the vibration mode to be suppressed, and control electronics driving piezoceramic actuators. The actuators are configured so as to oppose the natural bending of the structure, thereby mechanically stiffening it against vibration. Active damping of vibration offers the advantage of low mass, small size and can be effective at low as well as high frequencies, typically many kHz.

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To achieve control of vibration on essentially planar structures requires that the actuators are optimally situated. This position is the anti-node of the flexure with the largest amplitude. Frequently, two actuators are used, one each side of the structure, configured such that when one expands the other contracts, thereby providing the desired anti-bending moment.

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To provide maximum sensitivity for detecting vibration it is also necessary to place the sensor (which in the known arrangements is a strain gauge) on the anti-node of the flexure with the largest amplitude and this means in practice on the actuator itself. Clearly this conflicts with the above mentioned requirement. Co-location of the sensor on the actuator degrades the system performance because the sensor then measures the strain of the upper surface of the actuator, which is different from that of the panel or PCB. Location of either the sensor or actuator off the anti-node results in diminished sensing and actuation respectively. This problem is further compounded by the fact that the strain field developed by the actuator is non-linear, being a maximum immediately adjacent to the actuator and decaying to zero at the panel or PCB edges. Mathematical models predict that the optimum location for an off anti-node strain sensor is approximately equidistant between the actuator and panel or PCB edge, where the sensitivity is half that of the uncontrolled anti-node value.

An additional disadvantage of using the known strain sensor to detect vibration for this type of application is that the panel must flex in order to derive an input signal for the control electronics. Thus, low levels of vibration cannot be controlled since this implies infinite gain from the control system.

The present invention is concerned with overcoming the above discussed problem.

According to the present invention instead of measuring the vibration in terms of the deflection itself, e.g. by means of a strain gauge, the derivative of the displacement, namely acceleration, of the planar member is detected instead.

How the invention may be carried out will now be described by way of example only and with reference to the accompanying drawings in which:

Figure 1 illustrates schematically a known mounting arrangement for a sensor and actuator on a planar member;

Figure 2 is a fragmentary perspective view, to a larger scale, of the arrangement shown in figure 1;

Figure 3 is a schematic diagram illustrating the sensor/actuator control feedback loop; and

Figure 4 is similar to Figure 1 but illustrates the present invention.

Referring to Figure 1, in a known arrangement using a strain sensor the planar panel 1, the vibration of which is to be controlled, has a piezoelectric actuator 2 mounted on it, e.g. by means of adhesive and a strain sensor 3 mounted on the actuator 2 again by means of adhesive, for example.

The reason the actuator and sensor are mounted in the same position on the panel 1 is because this is the optimum position for both sensing any vibration of the panel and for applying a corrective force to the panel in order to reduce or eliminate that vibration. The position selected for mounting the actuator 2 and strain sensor 3 will depend upon the characteristics of the panel but would preferably be at the maximum anti-node of vibration.

There are a number of disadvantages with this known arrangement. Firstly, the strain sensor 3 must be subject to strain in order to produce an electrical output. Consequently the

panel must actually vibrate for the electronic control system to operate. This means in practice that there can be no control of the vibration below a certain minimum level of deflection of the panel 1, i.e. there is a dead zone where the active vibration control is ineffective.

5           In addition to this problem there is a further problem concerning the sensitivity of the arrangement in that by mounting the strain sensor 3 on the actuator 2 the sensor 3 is actually directly measuring the flexing of the actuator 2 and only indirectly measuring the flexing of the panel 1. Therefore, because the actuator 2 flexes less than the panel 1 it follows that the sensitivity of the strain sensor 3 to the flexing of the panel 1 is less than it would otherwise be  
10 if the strain sensor was mounted directly on the panel 1. However, if that were done the strain sensor 3 could not be co-located with the actuator with a respect to the anti-node of the vibrating panel 1 and although it would gain in sensitivity for having been mounted directly on the panel 1 it would lose in sensitivity because of being in an area which is subject to a lesser amplitude of flexing.

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Figure 2 shows the mounting of the actuator 2 on the panel 1 and the sensor 3 on the actuator 2 in more detail and Figure 3 shows the electrical control circuit whereby active vibration control is effected.

20           Referring to Figure 3, the sensor generates a voltage as a result of the piezoelectric actuator 2 being flexed by vibration of the panel . The output from the sensor 3 is amplified by an amplifier 4, filtered by a filter 5, phase inverted by an inverter 6 and the resulting signal applied to the piezoelectric actuator 2.

The application of this signal to the actuator has the effect of contracting the area of the actuator to in turn apply a similar force to the panel 1 in order to counteract the force tending to flex that panel into the shape shown in Figure 1(a).

5 Similarly at the point in the vibration cycle where the panel 1 is flexing in the opposite direction, shown in Figure 1(b), the effect of that flexing is to cause the sensor 3 to generate a signal which when applied to the piezoelectric actuator 2 will cause the latter to expand and thus tend to counteract the force causing the panel to flex into the configuration shown in Figure 1(b).

10 As indicated earlier in connection with Figure 1 there are a number of disadvantages with this known arrangement.

The present invention overcomes the disadvantages by the use of a sensor which is in the form of an accelerometer 7 instead in the form of a device 3 for measuring the strain. Thus with  
15 the present invention instead of the sensor 3 indirectly measuring the displacement of the panel 1 by measuring the displacement of the actuator 2, the accelerometer 4 of the present invention measures directly the rate of change of the displacement, i.e. the second derivative of the movement of the panel, in order to provide the correcting signal which is then applied to the piezoelectric actuator in the manner already described with reference to Figure 3.

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Because the accelerometer sensor 4 detects the actual movement of the panel 1 in the direction of the arrow A shown in Figure 4 (and not the surface expansion, or contraction of the actuator 2, and indirectly that of the panel 1 as does the strain sensor 3) the accelerometer sensor 4 directly detects the actual vibration of the panel 1.



Consequently by using the accelerometer sensor 4, in place of the strain sensor 3, the sensitivity of the arrangement is increased.

Furthermore, as a consequence of the accelerometer sensor 4 measuring deflection in the direct of the arrow A, because this deflection is the same for both the panel 1 and the actuator 2 there is no loss of sensitivity by having the sensor 4 mounted directly on the actuator 2. Consequently it is possible to co-locate both the actuator 2 and the sensor 4 in the same optimum position on the panel 1 without any consequential loss of sensitivity..

All accelerometers are internally referenced. This means it detects the acceleration to which it is subjected. If an accelerometer is fixed to a panel it will detect the acceleration of that point on the panel. If the entire structure on which the panel is mounted moves, the accelerometer will also detect that movement. Thus, if the panel moves, the control system will respond by stiffening the panel before it begins to deflect significantly.

It should be noted that the acceleration on the one hand and strain on the other hand of a vibrating panel are generally not in phase. It may therefore be thought that the use of an acceleration signal to control the actuator 2 and thus the vibration of the panel 1 would not be regarded as an appropriate solution to the above discussed problem. However, if the combined actuator 2 and sensor 4 unit is located at the maximum anti-node then the acceleration and the strain are in phase with the result that the control system can be made stable.

A panel excited to vibrate will do so at its fundamental resonant frequency. Positioning of the sensor/actuator unit on the fundamental anti-node therefore gives maximum suppression

of the vibration. If a strain sensor is not located on the fundamental anti-node the system sensitivity is decreased, as explained earlier. However if an accelerometer sensor is not located on the fundamental anti-node it will also be responsive to the acceleration of the structure to which the panel is attached. This disconnection between the sensing and actuating elements can easily result in an unstable control system. Hence it is important to locate an accelerometer sensor on the maximum anti-node.

In practice the piezoelectric actuator 2 and the accelerometer sensor 4 would be produced as a unit for securing to whatever planar element's vibration it was required to control.

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The accelerometer sensor 4 can be secured to the piezoelectric actuator 2 by any simple means such as by adhesives, solders or mechanical fastenings.

**CLAIMS**

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1. An active vibration damping device comprising a combined piezoelectric actuator and accelerometer mounted on it and fabricated as a unit.

2. A planar member having the device of Claim 1 mounted on it.

3. The arrangement of Claim 2 in which the device is mounted at the maximum anti-node of vibration of the planar member, when in use.

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4. The arrangement of Claim 2 or 3 incorporated in a control circuit.

5. A device substantially as hereinbefore described with reference to as and shown in Figure 4 of the accompanying drawings.

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6. The combination of the device of claim 5 together with a planar member substantially as hereinbefore described with reference to and as shown in Figure 4 of the accompanying drawings.

**Amendments to the claims have been filed as follows**

**CLAIMS**

1. A method of actively damping the vibrations of a vibrating planar member comprising mounting at the maximum anti-node of the vibrating planar member a device comprising a combined piezoelectric actuator and an accelerometer which are fabricated as a unit.  
5
2. A combined piezoelectric actuator and an accelerometer fabricated as a unit and for use in the method of Claim 1.
- 10 3. A method of actively damping the vibrations of a vibrating planar member, substantially as hereinbefore described with reference to and as shown in the accompanying drawings.
4. A device substantially as hereinbefore described with reference to as and shown in Figure 4 of the accompanying drawings.
- 15 5. The combination of the device of claim 5 together with a planar member substantially as hereinbefore described with reference to and as shown in Figure 4 of the accompanying drawings.



Application No: GB 9609871.0  
Claims searched: 1-6

Examiner: Steven Davies  
Date of search: 2 August 1996

**Patents Act 1977**  
**Search Report under Section 17**

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G3R-RBS,RBU ; H4J-JGA

Int Cl (Ed.6): G05D-19/02 ; G10K-11/178

Other: Online WPI

**Documents considered to be relevant:**

Category	Identity of document and relevant passage	Relevant to claims
X	GB 2260874 A (GEC-MARCONI) page 3,line 1-page 4,line 18	1-6
X	GB 2019695 A (MESSERSCHMITT-BOLKOW-BLOHM) page 2,lines 38-66	1-6
A	EP 0342040 A2 (CANON) e.g. page 3,lines 20-48	
A	US 5251863 (GOSSMAN et al) col.2,lines 8-20 ; Figs.2,3	

X Document indicating lack of novelty or inventive step  
Y Document indicating lack of inventive step if combined  
with one or more other documents of same category.

& Member of the same patent family

A Document indicating technological background and/or state of the art.  
P Document published on or after the declared priority date but before  
the filing date of this invention.  
E Patent document published on or after, but with priority date earlier  
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